Renewable and Sustainable Energy Reviews 21 (2013) 444–455

Contents lists available at SciVerse ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

How many jobs can the RES-E sectors generate in the Portuguese context?

C. Oliveira [a,b,*], D. Coelho [a,c], P. Pereira da Silva [a,d], C.H. Antunes [a,e]

[a] INESC Coimbra, Rua Antero de Quental, 199, 3030-030 Coimbra, Portugal
[b] ISCAC, Quinta Agrícola, Bencanta, 3040-316 Coimbra, Portugal
[c] Department of Electrical Engineering, ISEC, Rua Pedro Nunes, Quinta da Nora, 3030-199, Coimbra, Portugal
[d] Faculty of Economics of the University of Coimbra, Av Dias da Silva, 165, 3004-512 Coimbra, Portugal
[e] Department of Electrical and Computers Engineering, University of Coimbra, Polo II, 3030-030 Coimbra, Portugal

A R T I C L E I N F O

Article history:
Received 30 October 2012
Received in revised form
29 December 2012
Accepted 3 January 2013
Available online 7 February 2013

Keywords:
Employment effects
Input–Output analysis
Multiobjective interval linear programming (MOLP)

A B S T R A C T

In the last years Portugal has been at the forefront in the deployment of electricity from renewable energy sources (RES-E). The Portuguese national energy strategy 2020 (NES 2020) aims to reinforce Portugal's leadership in sustainable energy and to attain the ambitious goals set in the government programme, namely consolidating the renewable energies cluster in Portugal, which will represent approximately by 2020 more than three times the 35,000 jobs estimated in 2010 and further developing the industrial cluster related with energy efficiency, creating 21,000 new jobs.

The main purpose of this paper is to perform a prospective study and to discuss the various factors that influence the appraisal of sustainable systems integrating environmental, social and economic dimensions, mainly focusing on the RES-E jobs case by means of a multiobjective Input–Output model, based on current data availability.

Contents

1. Introduction . . . 444
2. I–O model description . . . 445
3. Employment multiplier concepts . . . 446
4. The MOLP I–O model with interval coefficients . . . 446
 4.1. Model constraints . . . 446
  4.1.1. Coherence constraints . . . 446
  4.1.2. Defining constraints . . . 447
 4.2. Objective functions . . . 447
5. Implementation of the methodology in Portugal . . . 447
6. Some illustrative results . . . 448
 6.1. Different shares of RES-E . . . 449
 6.2. RES-E basic equipment is domestically produced. . . . 452
7. Conclusions . . . 454
Acknowledgments . . . 454
References . . . 454

1. Introduction

The benefits of renewable energy are widely accepted by fostering a decrease in Green House Gases (GHG) emissions and an improvement in energy security. Moreover, it is commonly felt that the move towards a greener economy will create a large number of new jobs across many sectors and that this fact will act as a vital incentive to sustainable development and to economic

* Corresponding author: INESC Coimbra, Rua Antero de Quental 199, 3030-030 Coimbra, Portugal. Tel.: +351 239 851040; fax: +351 239 824692.
E-mail addresses: coliv@inescc.pt (C. Oliveira), dcoelho@isec.pt (D. Coelho), patsilva@fe.uc.pt (P. Pereira da Silva), cantunes@inescc.pt (C.H. Antunes).

1364-0321/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.rser.2013.01.011

growth. The exploitation of renewable energy sources in electricity generation is expected to have a crucial contribution to the overall rise of employment opportunities in several sectors, including equipment manufacturing, construction, administrative and service activities [29], but this claim stands on an uncertain footing. While studies often present renewable energy as a boost to the economy through the generation of large job growth (such as [3]) there are often overly optimistic or simplistic assumptions that lead to these results. In some cases reasonable assumptions are made, but selective reporting of results can lead to a false impression of job creation.

Studies analyzing the impact of job creation in the RES-E sector can be broadly categorized into two main categories: input–output (I–O) methods and analytical methods, both with their own distinct advantages and disadvantages [16, 30]. While I–O methods are easily used within a National scope, analytical methods are commonly used for regional or provincial studies (e.g., [3, 27]. On the other hand, since analytical methods usually account for direct employment effects only, traditional methods applied in jobs and economic impacts analysis mostly rely on I–O models to estimate employment creation or loss. This kind of models allows for the representation of the economy as a whole, recording the flows of goods and services industries trade with one another. Those flows are registered in an I–O matrix, simultaneously by origin and by destination which illustrates the relationship between producers and consumers as well as interdependencies of industries for a given year [17]. Therefore, these models allow capturing employment multiplier effects and macroeconomic impacts of shifts between sectors, accounting for losses in one sector created by the growth of another sector [5].

Many countries compile I–O tables for their economies at regular time intervals both as a national statistical requirement and for the purpose of providing detailed databases for policy analysis. Therefore, I–O analysis is an analytical tool adequate for the evaluation of the inter-relations between different economic activities being often applied to assess economy–energy–environment (E3) interactions [12].

I–O analysis limitations mainly refer to the hypotheses assumed within the model. In fact, this modelling technique is based on a set of assumptions that might be considered as its main drawbacks. The technical coefficients are considered as constant over time, there are no economies or diseconomies of scale in production or factor substitution and it is also assumed homogeneous output for each activity sector. Another issue is that, in general, final demand is exogenously determined. Finally, there is the assumption that there are no bounds for the capacity of production, that is, supply is supposedly infinite and perfectly elastic.

Albeit apparently these restraining assumptions limit the application of I–O analysis, it is possible to eliminate or avoid some of them through adequate adjustments. For instance, the uncertainty handling of the technical coefficients may be tackled through the use of interval or fuzzy programming techniques (see [23] and [4], respectively).

The use of I–O multipliers is particularly appropriate for evaluating the contribution of a particular industry (e.g., RES-E) to the economy and for performing the impact assessment of broad policy instruments. However, in order to get the whole picture of the impacts of an economic activity and an environmental impact assessment, a multi-objective analysis must be implemented as well [6]. Therefore, an overall analysis of the trade-offs regarding the conflicting axes of evaluation intrinsic to sustainable development will be performed by means of a multi-objective I–O model with interval coefficients, based on current data availability.

In the next section of this paper, the methodological framework used herein will be briefly presented, followed by the explanation of the implementation of the methodology in Portugal. Then, some illustrative results will be analyzed, considering different sources of uncertainty and scenarios and, finally, some final remarks and future work developments are drawn.

2. I–O model description

I–O matrices allow the representation of each sector's production process through a vector of structural coefficients that describes the relationship between the intermediate inputs consumed in the production process and the total output. The supply side is split into several processing industries that deliver their total output (production), for intermediate consumption or final demand. These relationships can be illustrated through the following equation:

$$x_i = \sum_{j=1}^{n} x_{ij} + y_i \tag{2.1}$$

where x_i is the output of sector i, x_{ij} is the input from sector i to sector j, and y_i is the total final demand for sector i.

The monetary values in the transactions matrices can then be converted into ratios called technical coefficients. This is done by dividing each cell of the domestic intermediate matrix by its column total (output at basic prices).

Considering the hypothesis of constant returns to scale, Eq. (2.1) becomes:

$$x_i = \sum_{j=1}^{n} a_{ij} x_j + y_i \tag{2.2}$$

in which the coefficients a_{ij} are the amount of input delivered by sector i to sector j per unit of sector's j output, known as technological coefficients (or direct coefficients).

The productive system at a national level can then be represented through the following basic I–O system of equations:

$$\mathbf{x} = A\mathbf{x} + \mathbf{y} \tag{2.3}$$

where A is a matrix of technological coefficients, $\mathbf{y}$ is a vector of final demand, and $\mathbf{x}$ is a vector of the corresponding outputs.

In order to finally calculate the output multipliers, one needs to derive Leontief inverse matrices.

Eq. (2.3) can then be rearranged to

$$\mathbf{x} = (I - A)^{-1}\mathbf{y}, \tag{2.4}$$

where I is the identity matrix with convenient dimensions and $(I-A)^{-1}$ is also known as the Leontief inverse. Each generic element, b_{ij}, of $(I-A)^{-1}$ represents the total amount directly and indirectly needed of good or service i to deliver one unit of final demand of good or service j.

Several empirical contributions have used the seminal methodological approach developed by Leontief. For instance, the evaluation of the inter-relations between different economic activities established by I–O analysis may be used to assess economy–energy–environment interactions—see, for example, the work developed by Gay and Proops [11], Peet [25] and Mu et al. [19]. Usually, these empirical applications of I–O analysis highlight the use of the Leontief inverse indicating the direct and indirect requirements of production that are needed to satisfy a particular final demand vector, being also known as the multiplier matrix.

3. Employment multiplier concepts

Although precise definitions vary, direct jobs are related to a sector's core activities, such as feedstock conversion, manufacturing, project development (including site preparation and installation) and operations and maintenance of the different components of the technology, or power plant, under consideration [30].

Therefore, the direct contribution of an industry in terms of output or employment can easily be measured by its level of output or the number of workers in the sector, respectively. Since the employment to output ratio is given for each sector in an I–O table, the overall significance and contribution of an industry to total employment can also be calculated by assuming that the sectorial employment ratios are fixed.

Indirect jobs refer to the "supplier effect" of upstream and downstream suppliers, corresponding to the industrial input sectors in the production and the operation and maintenance of renewable energy technologies. Examples might include the jobs required to extract and process raw materials, such as steel for wind turbine towers as well as positions in government ministries, regulatory bodies, consultancy firms and research organizations working on renewables [30].

Thus, the indirect contribution of an industry to either total output or employment is not simply observable unless the multiplier and flow-on effects are taken into account. Therefore, the employment multiplier may be interpreted as the impact on the overall employment if the final demand in sector j increases by one unit. The employment multiplier for sector j, E_j^m, is thus defined as follows:

$$E_j^m = \sum_{i=1}^{n} e_i b_{ij}, \tag{3.1}$$

where e_i denotes the number of persons with full time employment per one Euro output for each sector i, b_{ij} is the (i, j)th element of the closed Leontief inverse matrix and n is the number of sectors. These multipliers would represent the number of new jobs created expressed as total employment for every new employee to meet increased final demand of new output, but one may wish to relate the simple or total employment effect to an initial change in employment, not to final demand (and output) in monetary terms. In this situation the employment multiplier, E_j, is:

$$E_j = \sum_{i=1}^{n} \frac{e_i b_{ij}}{e_j} \tag{3.2}$$

4. The MOLP I–O model with interval coefficients

I–O analysis and linear programming (LP) are closely related. In its simplest form, I–O analysis may be regarded as a simple particular case of LP [8]. The use of the I–O methodology in the framework of LP models allows obtaining value-added information, which would not be possible to achieve with the separate use of both techniques. Inter/intra-sector relations embedded in I–O analysis allow designing the production possibility frontier. LP models enable choosing the optimum level of activities to optimize a given objective function, satisfying the production sector relations imposed by I–O analysis. Traditional studies, which use I–O analysis in the framework of LP, generally consider a single objective function, usually an aggregate economic indicator. However, in most real-world problems multiple, conflicting and incommensurate axes of evaluation of the merit of potential solutions are inherently at stake. In this context, mathematical programming models for decision support become more representative of reality if distinct aspects of evaluation are explicitly considered. In this context, an MOLP I–O model to deal with E3 interactions has been proposed elsewhere [23, 24]. Some changes are now incorporated into the model herein proposed: an updated data set of I–O symmetrical product by product tables for the total flows at basic and current prices of 2008, the construction of distinct vectors for the incorporation of RES-E production within the I–O matrix, the use of multipliers to obtain the impacts of RES-E on the overall employment and the consideration of different objective functions more consistent with the aim of this study (the maximization of Gross Domestic Product—GDP as a proxy for economic growth, the maximization of the overall employment in the economy and the maximization of RES-E production).

The model includes two main types of constraints: coherence constraints (based on I–O analysis) and defining constraints. The economic and environmental defining constraints with interval coefficients have been imposed with interval (upper/lower) bounds consistent with data available [14,18].

4.1. Model constraints

The matrices are given in capital letters, the vectors in small bold letters, the scalar elements are given as small letters and the letter **T** designates the transpose of a matrix or a vector.

4.1.1. Coherence constraints

The intermediate consumption and final demand of goods or services of each activity sector shall not exceed the total amount available from national production and competitive imports of that same good or service.

Energy and non-energy branches:

$$A\mathbf{x} + D\mathbf{y} \le \mathbf{imp}^c + \mathbf{x} \tag{4.1}$$

A is the technical coefficients (product-by-product) matrix, where each element is the amount of good or service i needed to produce a unit of good or service j. This matrix has interval coefficients and is given in hybrid units (toe/million of Euros or million of Euros/toe). D is the diagonal matrix whose main diagonal corresponds to the coefficients of consumption of energy and non-energy commodities by the final demand sectors (households and non-profit institutions serving households—NPISH, public consumption, gross fixed capital formation, acquisitions less disposals of valuables and stock changes and exports);

$\mathbf{x}$ is the national output vector.
$\mathbf{y}$ is the final demand vector.
$\mathbf{imp}^c$ is the vector of competitive imports with no endogenous substitutes (for energy commodities only).

I–O energy consumption coefficients are given as intervals to cope with their uncertainty. The upper and lower bounds of these intervals correspond, respectively, to a more or less pessimistic stance, regarding the energy coefficient settings for the planning horizon (2020). The coefficient set leading to the broadest feasible region incorporates an improvement of the energy efficiency measured through the energy use coefficients of the different activity branches. It takes into consideration a reduction of 5% for the electricity, diesel oil and gasoline consumption coefficients. The energy coefficient setting leading to the more stringent version of the feasible region considers an increase of 5% in natural gas consumption coefficients regarding co-generation and thermoelectricity generation, since national authorities are replacing fuel oil consumption by natural gas.

4.1.2. Defining constraints

4.1.2.1. Economic constraints. Several consumption representations are considered in the model: the households' consumption in the territory (consumption in the territory by resident and non-resident households), the residents' (households and NPISH) consumption, the resident households' domestic consumption which is linearly dependent on the available income, and the tourism imports given as a proportion of the resident household consumption [21].

With respect to foreign trade, it is possible to obtain: total exports (excluding and including tourism) at constant FOB (free on board) prices, exports at constant purchasers' prices, total exports (excluding tourism) at CIF (cost, insurance and freight) prices, total imports (excluding tourism) at CIF prices, and total imports (excluding and including tourism) at FOB constant prices.

Gross domestic product (GDP) is computed according to the production approach ($\mathrm{gdp}_{\mathrm{prod}}$) and the expenditure approach (gdp).

GDP production approach:

$$\mathrm{gdp}_{\mathrm{prod}} = \mathrm{gav} + \mathbf{ts} \tag{4.2}$$

where gav is the gross added value (see (4.3)) and **ts** is the sum of the components of vector of net taxes **ts** (see (4.4)).

Gross added value (gav):

$$\mathrm{gav} = \mathbf{a}_w^{\mathbf{T}}\mathbf{x} + \mathbf{a}_t^{\mathbf{T}}\mathbf{x} - \mathbf{a}_s^{\mathbf{T}}\mathbf{x} + \mathbf{a}_{os}^{\mathbf{T}}\mathbf{x} \tag{4.3}$$

where $\mathbf{a}_{\mathrm{w}}$, $\mathbf{a}_{\mathrm{t}}$, $\mathbf{a}_{\mathrm{s}}$, $\mathbf{a}_{\mathrm{os}}$ are the vectors with the proportion of wages, taxes, subsidies, gross operating surplus and gross mixed incomes on the total output of each branch.

Net taxes (**ts**):

$$\mathbf{ts} = A_{\mathbf{ts}}\mathbf{x} + D_{\mathbf{ts}}\mathbf{y} \tag{4.4}$$

where $A_{\mathbf{ts}}$ is the matrix with the proportion of net taxes on goods and services on the total output of each branch, and $D_{\mathbf{ts}}$ is the diagonal matrix whose main diagonal is the vector with the percentages of net taxes on goods and services aimed at household/NPISH/public consumption/gross fixed capital formation/changes in inventories/acquisitions less disposals of valuables/exports on their respective total values.

GDP expenditure approach

$$\mathrm{gdp} = \mathrm{rc} + \mathrm{g} + \mathrm{gfcf} + \mathrm{sc} + \mathrm{aldv} + \mathrm{expfob} - \mathrm{mfob} \tag{4.5}$$

where rc is the resident's consumption, g is the public consumption, gfcf is the gross fixed capital formation, sc is changes in inventories, aldv is acquisitions less disposals of valuables, expfob is exports at FOB purchasers' prices (including tourism) and mfob is imports at FOB prices (including tourism).

The GDP at current prices is obtained from the distinct components of GDP (expenditure approach) at constant prices, which are multiplied by the corresponding deflators.

The residents' disposable income is equal to the difference between the National Available Income and the sum of the available income of corporations and public administration.

The employment level (emp) is obtained by using labour gross productivity coefficients ($\mathbf{l}^{\mathbf{T}}$) for each branch:

$$\mathrm{emp} = \mathbf{l}^{\mathbf{T}}\mathbf{x} \tag{4.6}$$

Energy imports (energy external dependence) are obtained in the following way:

$$(\mathbf{e}_1)^{\mathbf{T}}\mathrm{imp}^c + (\mathbf{e}_2)^{\mathbf{T}}(A_m^{nc}\mathbf{x} + D_m^{nc}\mathbf{y}) \tag{4.7}$$

where $\mathbf{e}_1$ and $\mathbf{e}_2$ are vectors of ones with convenient dimensions, A_m^{nc} is the matrix of non-competitive import coefficients of energy (given as intervals to capture uncertainty) and D_m^{nc} is the diagonal matrix whose main diagonal is the vector with the percentages of non-competitive imports of energy goods aimed at household/NPISH/public consumption/gross fixed capital formation/changes in inventories/acquisitions less disposals of valuables/exports on their respective total values (also given as interval coefficients).

4.1.2.2. Environmental constraints. CO_2 emissions from fuel combustion are easily obtained from the I–O table, where the total fuel use is the total amount of fuel production plus imports. Nevertheless, the energy use for exports and investment shall not be taken into account in the emission computations [26].

$$\mathbf{co}_2 = D_{ttj}D_cD_o[A_E\mathbf{x} + D_E\mathbf{y} - N_E\mathbf{y} - N_E\mathbf{x}]\left(\tfrac{44}{12}\right)\left(10^{-3}\right) \tag{4.8}$$

where D_{ttj} is the diagonal matrix with conversion factors from toe to terajoules (TJ) for each type of energy, $D_c$is the diagonal matrix, whose main elements are the carbon (C) emission factors for each type of energy (given as interval coefficients), $D_o$is the diagonal matrix, whose main elements are the fractions of carbon oxidized for each type of energy, A_E is a sub-matrix of matrix A with the energy consumption coefficients, D_E is a sub-matrix of matrix D with the energy consumption coefficients, N_E is the matrix with the coefficients of energy use with non-energy purpose for each branch and 44/12 is the ratio between the molecular weights of CO_2 and C.

4.2. Objective functions

The allocation of energy resources shall be made having in mind that the energy sector is a part of the economic system as a whole and that energy planning requires the consideration of economic, social, energy and environmental objectives, the four main pillars of sustainable development. In this way, the model herein proposed considers the following objective functions: (a) Maximization of GDP (economic growth); (b) Maximization of the level of employment (social welfare); (c) Maximization of RES-E production (energy and environmental concerns).

5. Implementation of the methodology in Portugal

The I–O symmetrical product by product tables for total flows at basic prices at current prices of 2008 herein used were produced by the Portuguese Department of Foresight and Planning and consist of 64 production sectors [7]. A hybrid I–O unit's matrix has also been adjusted for the base year of this study based on the Portuguese Energy Balance and on the energy statistics available at the Portuguese Directorate General of Energy and Geology for the base year of this study (2008), although a monetary unit's matrix has been used to compute the RES-E employment multipliers.

The most straightforward way to assess employment effects is to collect employment data directly from the units involved in the considered activities. However, in most countries, such as Portugal, the number of other related RES-E activities are still few and reliable data regarding employment inputs are either scarce, missing or vary significantly from case to case. Therefore, the estimation of direct and indirect employment in physical terms was performed using assumptions based on several sources. The total level of full time employment equivalent (FTE) in RES-E production was based on National Statistics Data on Environmental Activities [20]. For the biomass power generation units, a number of 220 direct employments were estimated based on a survey which allowed concluding that, in average, each power generation unit was responsible for the direct employment of 20 persons [13]. For the solid waste disposal (SWD) units 10 direct jobs were considered for each unit, according to a similar study

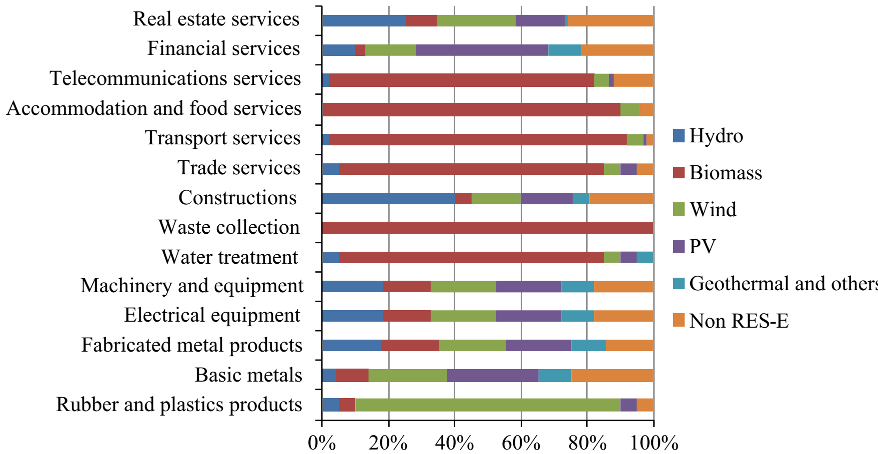


Fig. 1. Cost structure allocation for the production of different RES-E types.

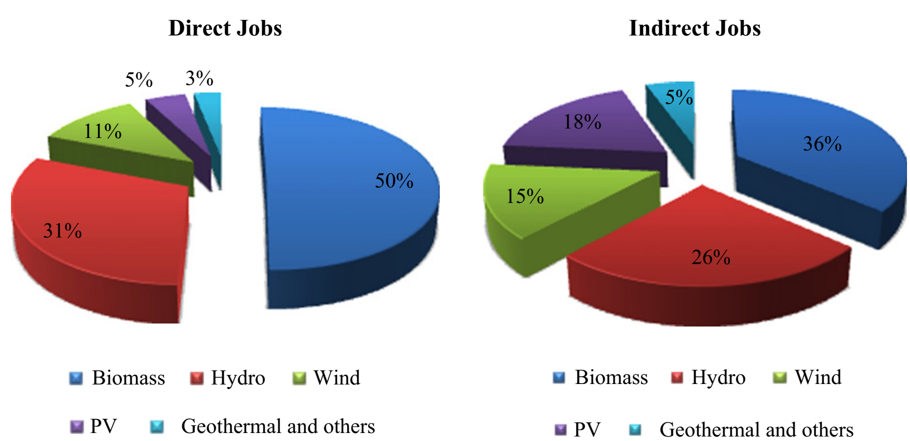


Fig. 2. Estimated share of direct and indirect jobs in 2008.

[31]. For the mini-hydro power generation units and since most of these units operate automatically and with few maintenance requirements, we have considered 1.5 persons employed for each unit (see also ADENE [2]). Big hydro plants only employ permanently 85 people [28]. For wind we have assumed according to EWEA [10] that direct jobs only refer to operation and maintenance which account for 11% of 800. PV is responsible for about 15 direct jobs in Amareleja plant [1] and an average of 10 in other two PV plants [28]. For geothermal energy we have considered the same factor of 0.74 jobs per MW installed used in [15] and in case of ocean energy we have considered a factor of 0.32 jobs per MW installed used in [15,9]. The remaining employments were allocated to biogas.

New I–O vectors have been constructed for each source: hydro, wind, PV, biomass (SWD, biomass and biogas) and geothermal. Fig. 1 shows the intermediary inputs structure used to build these new I–O vectors, which was based on [29] and on the Portuguese RES-E production share.

Fig. 2 illustrates the estimated share of direct and indirect jobs for each RES-E type on total direct and indirect jobs, respectively. Fig. 3 shows the share of direct and indirect jobs for each RES-E type on each RES-E type total jobs.

The upper bound imposed on RES-E for the time horizon of 2020 was based on the RES-E production capacity by the Portuguese National RES-E Action Plan and considering the same rate of production of 2010. We have also considered an upper target on the level of FTE consistent with the values attained in 2010.

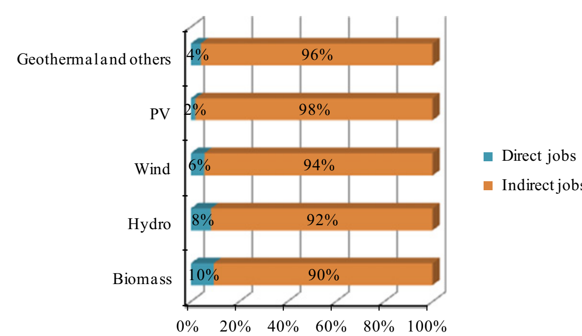


Fig. 3. Share of direct and indirect jobs for each RES-E type in 2008.

Interval coefficients were only considered for the economic constraints and environmental defining constraints. Different scenarios were also considered for RES-E in the framework of these interval coefficients.

6. Some illustrative results

The first solutions were obtained considering a business as usual scenario (BAU) corresponding to the base year of this study (2008) and three distinct scenarios for the share of RES-E regarding their corresponding shares on total RES-E production (see Table 1). Finally, a scenario was also considered where the RES-E

basic equipment (either from rubber and plastics, basic metals, metal products, electrical equipment or machinery sectors) is domestically produced (see Fig. 10).

Table 1
Share of each RES-E on total RES-E production.

	BAU (2008) (%)	SCENI (%)	SCENII (%)	SCENIII (%)
Hydro	39	45	50	25
Biomass	30	20	20	35
Wind	30	30	28	30
PV	0,2	3	1	9
Geothermal and others	1	2	1	1

6.1. *Different shares of RES-E*

An extended pay-off table containing all individual optimal values for each objective function either with the broadest versions of the feasible region and most favourable versions of the objective functions (best case scenario) or with stringent versions of the feasible region and less favourable versions of the objective functions (worst case scenario) is presented for each RES-E scenario considered (see Table 2). The main diagonal of each pay-off table corresponds to the ideal solution in the best and worst case scenarios considered (the individual optimal solutions for each objective function either in a best case or worst case scenario). GDP ($gdp=[gdp_{worst}, gdp_{best}]$) is given in millions of Euros, the level of Employment ($emp=[emp_{worst}, emp_{best}]$) is

Table 2
Extended pay-off tables for each RES-E scenario.

BAU	Max gdp		Max emp		Max res-e		SCEN I	Max gdp		Max emp		Max res-e	
	Sol 1	Sol 2	Sol 3	Sol 4	Sol 5	Sol 6		Sol 7	Sol 8	Sol 9	Sol 10	Sol 11	Sol 12
gdp_{Best}	**236.144**	216,318	222,229	203,415	202,259	177,510	gdp_{Best}	**236,118**	216,318	207,821	176,106	154,200	118,631
gdp_{Worst}	218,492	**200,866**	205,437	188,441	187,300	163,331	gdp_{Worst}	218,492	**201,557**	194,365	165,943	143,830	112,809
emp_{Best}	5,435	4,602	**5,600**	5,600	4,520	4,116	emp_{Best}	5,375	5,039	**5,600**	5,600	3,434	2,874
emp_{Worst}	5,435	4,602	5,600	**5,600**	4,520	4,116	emp_{Worst}	5,375	5,039	5,600	**5,600**	3,434	2,874
$res\text{-}e_{Best}$	1627,764	1954,211	1627,764	1941,765	**5010,039**	5010,039	$res\text{-}e_{Best}$	2273,369	1953,950	2015,127	1794,410	**5010,039**	5010,039
$res\text{-}e_{worst}$	1627,764	1954,211	1627,764	1941,765	5010,039	**5010,039**	$res\text{-}e_{worst}$	2273,369	1953,950	2015,127	1794,410	5010,039	**5010,039**
SCEN II	Max GDP		Max EMP		Max RES-E		SCEN III	Max GDP		Max EMP		Max RES-E	
	Sol 13	Sol 14	Sol 15	Sol 16	Sol 17	Sol 18		Sol 19	Sol 20	Sol 21	Sol 22	Sol 23	Sol 24
gdp_{Best}	**236,127**	216,318	196,093	180,306	123,313	141,612	gdp_{Best}	**236,112**	216,318	236,009	186,816	138,486	118,535
gdp_{Worst}	218,492	**202,254**	183,379	169,797	117,341	131,826	gdp_{Worst}	218,492	**201,524**	218,492	174,630	129,971	112,718
emp_{Best}	5,395	4,595	**5,600**	5,600	2,711	3,327	emp_{Best}	5,367	5,344	**5,600**	5,600	3,120	2,872
emp_{Worst}	5,395	4,595	5,600	**5,600**	2,711	3,327	emp_{Worst}	5,367	5,344	5,600	**5,600**	3,120	2,872
$res\text{-}e_{Best}$	2276,566	1962,095	1829,883	1827,200	**5010,039**	5010,039	$res\text{-}e_{Best}$	1855,286	4782,185	1855,286	1855,286	**5010,039**	5010,039
$res\text{-}e_{worst}$	2276,566	1962,095	1829,883	1827,200	5010,039	**5010,039**	$res\text{-}e_{worst}$	1855,286	4782,185	1855,286	1855,286	5010,039	**5010,039**

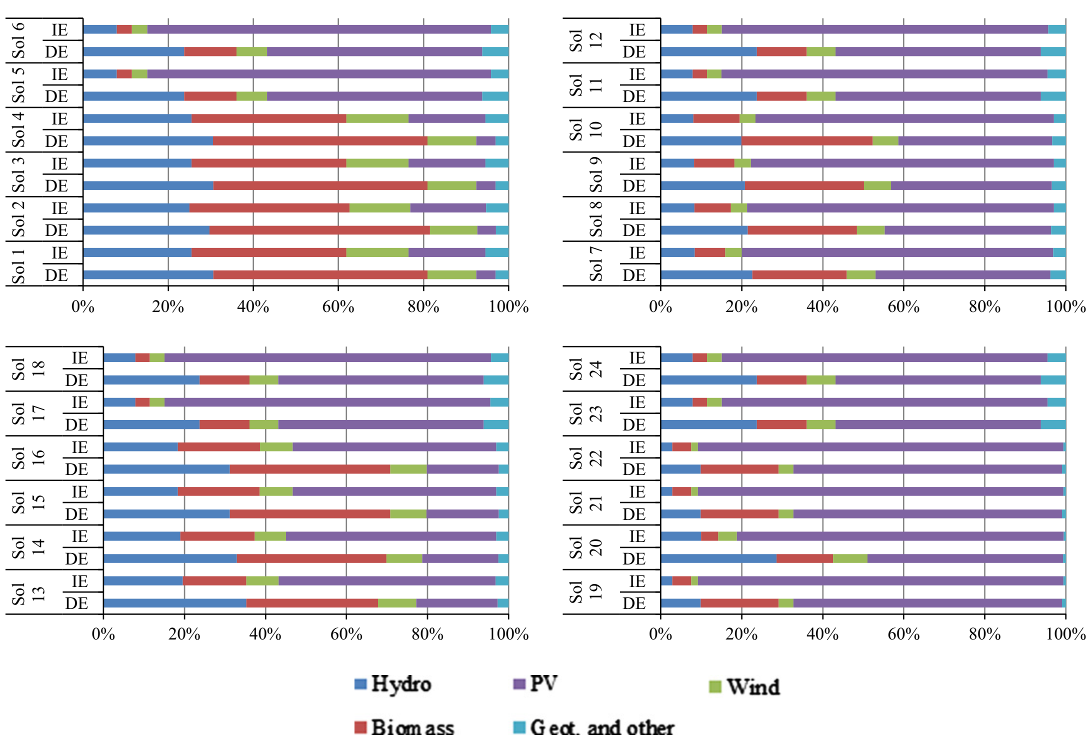


Fig. 4. Contribution of each RES-E type to DE and IE in each solution obtained in Table 2.

given in thousand of persons and RES-E (res-e=[res-e$_{worst}$, res-e$_{best}$]) production is given in toe (tons of oil equivalent).

The extended pay-off tables obtained (see Table 2) highlight the antagonist nexus between economic growth and RES-E production and the overall employment attained in the economy and RES-E production. Whenever RES-E production is maximized (solutions 5, 6, 11, 12, 17, 18, 23 and 24) the level of GDP and the overall level of employment attained suffer a negative impact. This fact confirms the main criticisms on RES-E production, usually citing that Government subsidies for their production may drive up costs and cost jobs or may furthermore crowd out other business investment.

Fig. 4 illustrates the contribution of each RES-E both to direct (DE) and indirect employment (IE) in the economy. The NES 2020 targets regarding RES-E employment are achieved with the maximization of RES-E production in all the scenarios considered (see Fig. 5), but compromising economic growth and the global level of employment attained. Scenario III with the highest increase of PV on RES-E production also allows achieving NES 2020 targets regarding RES-E employment in solution 20 (with the optimization of GDP).

According to BAU scenario RES-E production of hydro and biomass contribute with the highest employment shares whenever GDP and the level of the overall employment are maximized. PV achieves the highest share on RES-E employment if total RES-E production is maximized according to all scenarios herein considered.

However, neither RES-E job studies nor their critiques typically include avoided environmental costs or other potential benefits (e.g., less imported fossil fuel). Therefore, the assessment of imported primary and secondary energy (in toe) and CO_2 emissions (in Giga grams—Gg) resulting from fossil fuel combustion either in best or worst case scenarios (with more efficient and less efficient carbon intensity factors) are illustrated for each solution in Figs. 6 and 7, respectively.

The antagonism between economic growth and the environmental impacts attained becomes clear in Fig. 7, with CO_2 emissions reaching the highest levels in the solutions which

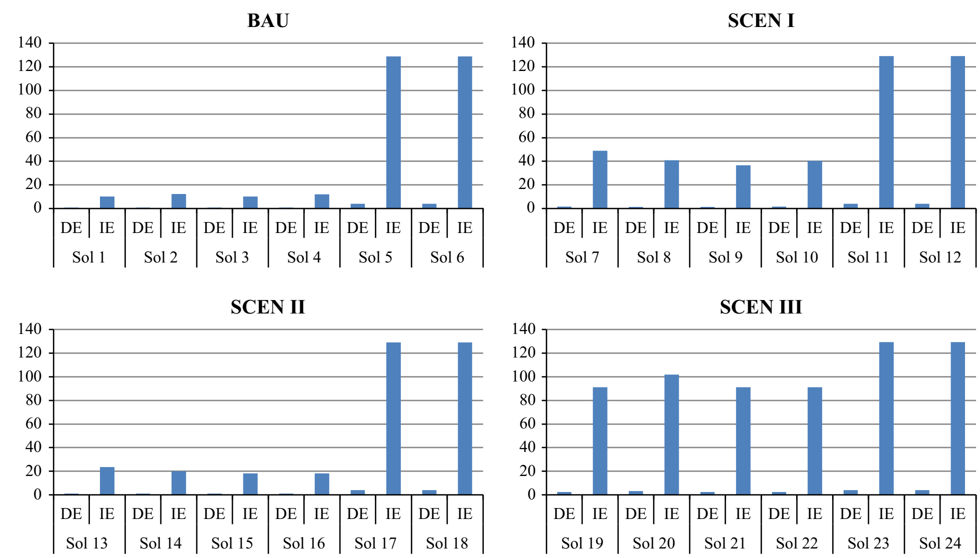


Fig. 5. Contribution of RES-E to total DE and IE in each solution obtained in Table 2.

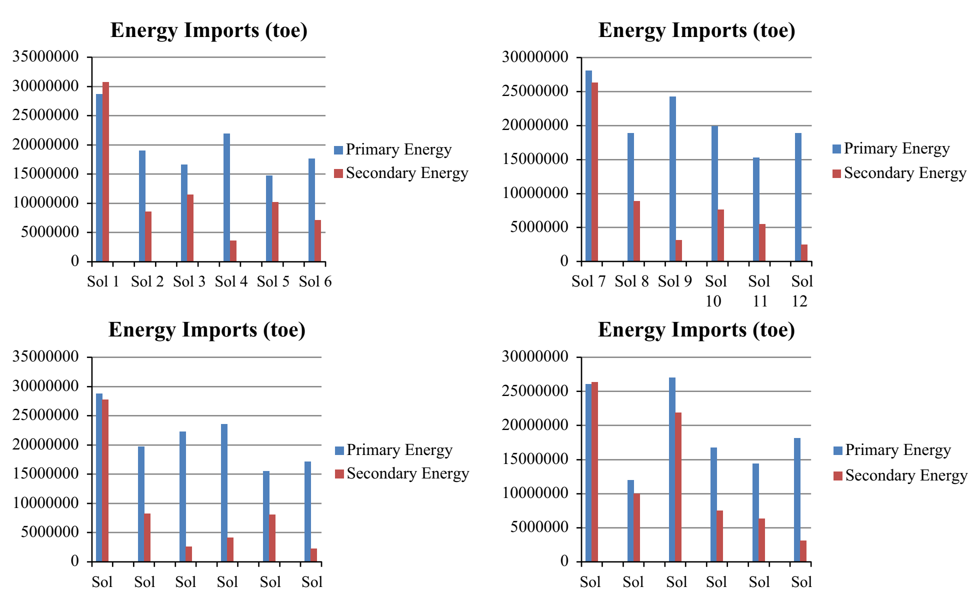


Fig. 6. Energy imports in each solution obtained in Table 2.

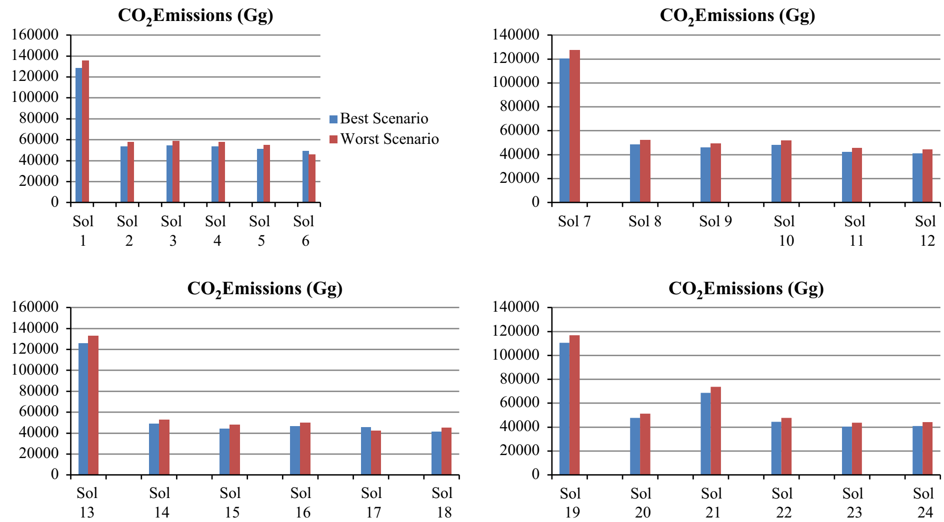


Fig. 7. CO_2 emissions from fossil fuel combustion in each solution obtained in Table 2.

Table 3
Minimization of the lower bound of the worst possible deviation.

	BAU		SCEN I		SCEN II		SCEN III	
	Optimistic stance		Optimistic stance		Optimistic stance		Optimistic stance	
	Best scenario Sol 25	Worst scenario Sol 26	Best scenario Sol 29	Worst scenario Sol 30	Best scenario Sol 33	Worst scenario Sol 34	Best scenario Sol 37	Worst scenario Sol 38
gdp_{Best}	218,152	216,318	233,578	204,511	218,152	202,279	213,678	204,730
gdp_{Worst}	204,040	201,624	218,492	191,201	204,040	189,111	198,956	191,404
emp_{Best}	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600
emp_{Worst}	5,600	5,600	5,600	5,600	5,600	5,600	5,600	5,600
$res\text{-}e_{Best}$	5010,039	5010,039	5010,039	5010,039	5010,039	5010,039	5010,039	5010,039
$res\text{-}e_{Worst}$	5010,039	5010,039	5010,039	5010,039	5010,039	5010,039	5010,039	5010,039

Table 4
Minimization of the upper bound of the worst possible deviation.

	BAU		SCEN I		SCEN II		SCEN III	
	Pessimistic stance		Pessimistic stance		Pessimistic stance		Pessimistic stance	
	Best scenario Sol 27	Worst scenario Sol 28	Best scenario Sol 31	Worst scenario Sol 32	Best scenario Sol 35	Worst scenario Sol 36	Best scenario Sol 39	Worst scenario Sol 40
gdp_{Best}	218,505	216,318	218,505	216,318	218,505	216,318	218,505	216,318
gdp_{Worst}	204,368	202,258	203,637	201,741	203,630	202,246	203,580	202,249
emp_{Best}	5,091	5,600	5,065	4,362	4,457	4,451	4,903	4,682
emp_{Worst}	5,091	5,600	5,065	4,362	4,457	4,451	4,903	4,682
$res\text{-}e_{Best}$	4599,934	3027,470	3246,139	3591,141	4722,173	3027,470	4828,455	3780,650
$res\text{-}e_{Worst}$	4599,934	3027,470	3246,139	3591,141	4722,173	3027,470	4828,455	3780,650

optimize GDP either in a best or worst case scenario or with different shares of RES-E production. As it would be expected with the maximization of RES-E production the lowest levels of CO_2 emissions are always obtained. Secondary energy imports also reach the lowest levels with the maximization of RES-E production (see Fig. 6). Nevertheless, the weight of RES-E production in gross domestic electricity consumption (production plus imports less exports) indicates that the maximization of RES-E production will lead to higher levels of electricity production than the domestic needs.

The approach used to obtain compromise solutions to the MOLP model based on I–O analysis with interval coefficients considers two surrogate deterministic problems, considering the minimization of the worst possible deviation of the interval objective functions from their corresponding interval ideal solutions [22]. The interval ideal solutions were computed (see Table 2) considering both extreme versions of the objective functions and the feasible region. The solutions are then obtained by minimizing the upper bound (pessimistic stance) or the lower bound (optimistic stance) of the worst possible deviation of each objective function from its interval ideal solution.

The values attained for each objective function in best and worst case scenarios for each scenario of RES-E production, considering the minimization of the lower bound and the minimization of the upper bound of the worst possible deviation of each objective function from its interval ideal solution, are given in Tables 3 and 4, respectively. For illustrative purposes we will only describe further the solutions obtained with a pessimistic

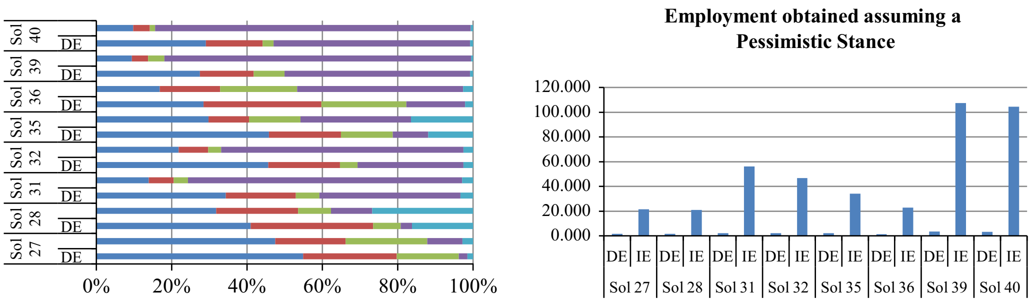


Fig. 8. Contribution of RES-E to DE and IE in each solution obtained in Table 4.

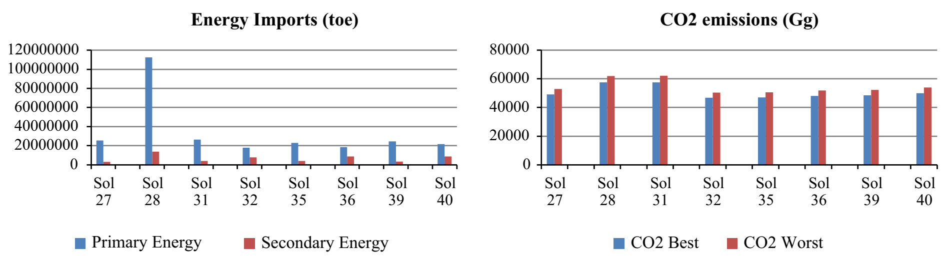


Fig. 9. Energy imports and CO_2 emissions in each solution obtained in Table 4.

stance (which in our opinion are closer to prospective reality). Solutions 25, 26, 29, 30, 33, 34, 37 and 38 that are obtained with an optimistic stance (that is, with the minimization of the lower bound of the worst possible deviation) always achieve in every RES-E scenario herein considered the optimal level of RES-E production and the optimal level of employment (see Table 3).

The solutions obtained by adopting a pessimistic stance allow reaching a weight of RES-E production in gross domestic electricity consumption from 57% (solution 31) to 115% (solution 39). Solution 28 (Scenario BAU) allows obtaining the highest overall employment level; however, the level of total RES-E employment (22,531 jobs) obtained in this solution is quite far from its NES 2020 target (see Fig. 8). Solutions 39 and 40 allow reaching NES 2020 target, but at the expense of a lower overall employment value, regarding solution 28. Nevertheless, solution 39 has the third highest overall employment level, regarding these last solutions obtained (Table 4).

Although solution 28 allows achieving the highest overall employment, it also leads to the highest levels of primary energy imports (Fig. 9) and the second highest levels of CO_2 emissions. On the other hand, solution 39 (with the highest level of RES-E production regarding solutions of Table 4) allows reaching the lowest levels of secondary energy imports.

6.2. RES-E basic equipment is domestically produced.

A scenario was also considered where the basic RES-E equipment (either from rubber and plastics, basic metals, metal products, electrical equipment or machinery sectors) is considered to be domestically produced, thus internalizing the import values on domestic production coefficients (see Fig. 10). A pay-off table containing all individual optimal values for each objective function either in a best or worst case scenario is also presented for this additional scenario (see Table 5).

The pay-off table obtained (see Table 5) highlights once more the antagonist nexus between economic growth and RES-E production and the overall employment attained in the economy and RES-E production (the lowest levels of RES-E production are obtained with the maximization of GDP—solution 41) and the lowest level of overall employment is obtained in the solution which optimizes RES-E production—solution 45). Nevertheless,

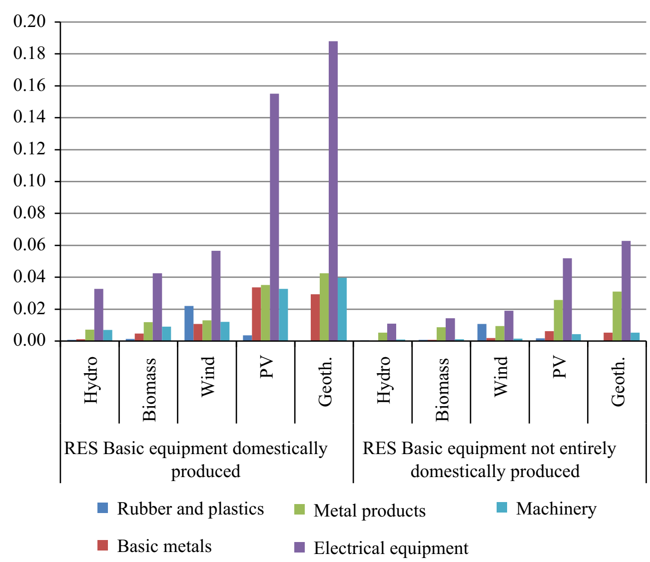


Fig. 10. Coefficients of production of RES-E (Euro/Euro).

Table 5
Pay-off table in the best and worst case scenario.

SCEN IV	Max GDP		Max EMP		Max RES-E	
	Sol 41	Sol 42	Sol 43	Sol 44	Sol 45	Sol 46
gdp_{Best}	**236,144**	216,318	206,991	216,318	233,487	211,533
gdp_{Worst}	218,492	**202,257**	193,588	200,353	218,492	197,028
emp_{Best}	5,436	5,600	**5,600**	5,600	4,860	5,600
emp_{Worst}	5,436	5,600	5,600	**5,600**	4,860	5,600
$res\text{-}e_{Best}$	1627,764	1893,289	1775,402	2031,702	**5010,039**	5010,039
$res\text{-}e_{Worst}$	1627,764	1893,289	1775,402	2031,702	5010,039	**5010,039**

with this new data set the employment level reaches the upper bound imposed in solutions 42 ($_{maximum}$ of GDP in a worst case scenario), 43 and 44 ($_{maximum}$ of Employment) and 46 ($_{maximum}$ of RES-E production in a worst case scenario). With this new

scenario of coefficients (considering domestic production of RES-E basic equipment) it is possible to reconcile the antagonism nexus of RES-E production and economic growth and the overall employment attained (see, for example, solution 46).

Fig. 11 illustrates the contribution of RES-E both to direct (DE) and indirect employment (IE) in the economy. The NES 2020 targets regarding RES-E employment are achieved only with the maximization of RES-E production, but without compromising significantly economic growth and the overall level of employment (see solution 46).

The assessment of imported primary and secondary energy (in toe) and CO_2 emissions (in Gg) resulting from fossil fuel combustion either in best or worst case scenarios (with more efficient and less efficient carbon intensity factors) are illustrated for each solution in Fig. 12.

The antagonism between economic growth and the environmental impacts attained becomes once more clear in Fig. 12, with CO_2 emissions reaching the highest levels in the solutions which optimize GDP in a best case scenario (solution 41). With the maximization of RES-E production low levels of CO_2 emissions are always obtained, albeit GDP is not much compromised in solutions 45 and 46. Secondary energy imports also reach the lowest levels with the maximization of RES-E production (see solutions 45 and 46 of Fig. 12). Nevertheless, the weight of RES-E production in gross domestic electricity consumption (production plus imports less exports) indicates that the maximization of RES-E production will lead once more to higher levels of electricity production than the domestic needs.

The values reached for each objective function in best and worst case scenarios, considering the minimization of the upper bound of the worst possible deviation of each objective function from its interval ideal solution are given in Table 6.

Surprisingly, the best employment and RES-E output results are obtained with an optimistic stance, but at the expense of a reduction of GDP, highlighting once more the trade-off between RES-E output and GDP.

Fig. 13 illustrates the contribution of RES-E both to direct and indirect employment in the economy. The NES 2020 targets regarding RES-E employment are achieved with the optimistic stance (solutions 47 and 48), mainly because of the PV sector.

The assessment of imported primary and secondary energy (in toe) and CO_2 emissions (in Gg) resulting from fossil fuel combustion either in best or worst case scenarios (with more efficient and less efficient carbon intensity factors) is illustrated for each solution in Fig. 14.

Although with an optimistic stance the output of the RES-E sector reaches a higher value, higher CO_2 emissions and primary imports of energy are obtained with this new scenario of coefficients. This is the result of considering the RES-E basic equipment domestically produced from activity sectors (rubber and plastics, basic metals, metal products, electrical equipment or machinery sectors) highly intensive on energy consumption.

The solution search process for prospective purposes might continue as long as the scrutiny of new solutions is needed. Other scenarios could also be considered in order to compute new solutions. In this context, another limitation regarding this type of modelling approach refers to the I–O data present in this study which is from 2008 (nevertheless, the I–O tables used herein were released in December 2011), being somehow out-of-date, because of the recent Portuguese effort in boosting green investment, namely RES-E production. We have tried to overcome this particular limitation by using interval data and distinct scenarios. Nevertheless, it is impossible to tackle the entire uncertainty herein involved.

Table 6
Minimization of the upper bound and lower bound of the worst possible deviation.

	RES-E basic equipment domestically produced			
	Optimistic Stance		Pessimistic stance	
	Best scenario Sol 47	Worst scenario Sol 48	Best scenario Sol 49	Worst scenario Sol 50
gdp_{Best}	210,019	205,768	218,505	216,318
gdp_{Worst}	196,423	192,378	204,367	202,254
emp_{Best}	5,600	5,600	4,614	4,644
emp_{Worst}	5,600	5,600	4,614	4,644
$res\text{-}e_{Best}$	5010,039	5010,039	3246,139	3027,470
$res\text{-}e_{Worst}$	5010,039	5010,039	3246,139	3027,470

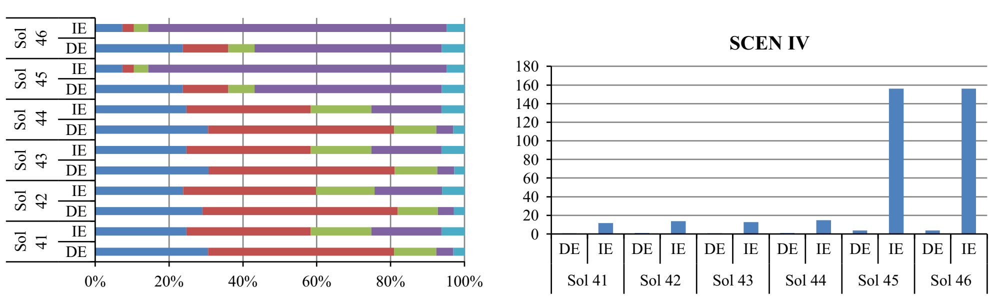


Fig. 11. Contribution of RES-E to total DE and IE in each solution obtained in Table 5.

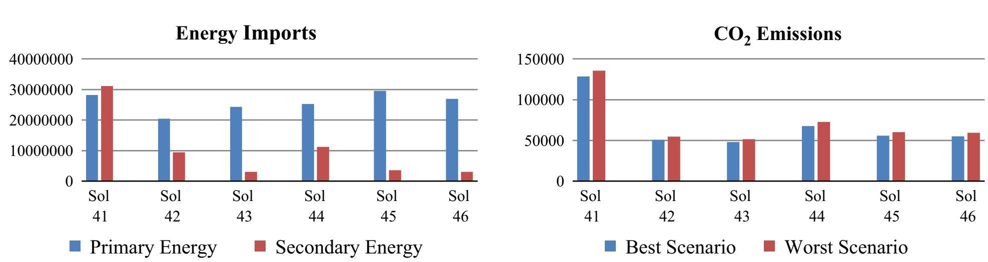


Fig. 12. Energy imports and CO_2 emissions in each solution obtained in Table 5.

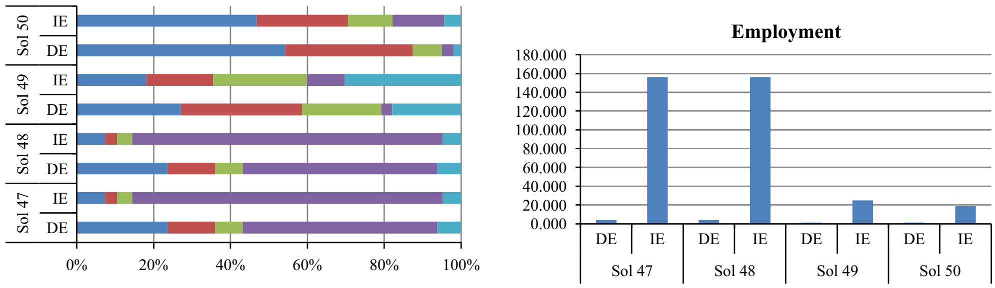


Fig. 13. Contribution of RES-E to total DE and IE in each solution obtained in Table 6.

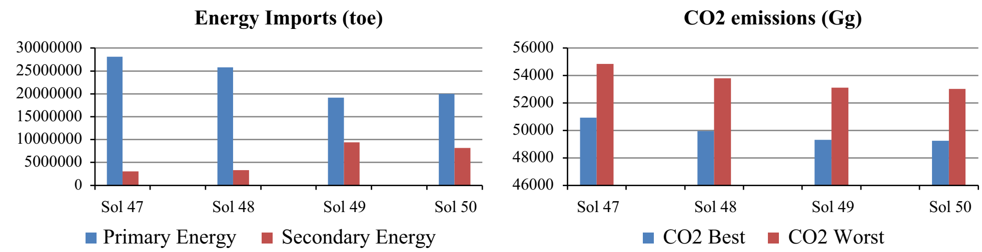


Fig. 14. Energy imports and CO_2 emissions in each solution obtained in Table 6.

7. Conclusions

A model approach is herein presented which entails a prospective assessment of several factors with impact on energy sustainable systems, incorporating energy, environmental, social and economic concerns. The analysis performed highlights the trade-offs among three objective functions: maximization of GDP, maximization of the overall employment level and maximization of RES-E production, obtaining a comprehensive analysis of the RES-E industry employment. The prospective results obtained according to current available data suggest that the targets imposed regarding employment generation in the RES-E sectors in the National Energy Strategy for 2020 are achieved only under extreme assumptions (that is, with the maximization of RES-E production) either according to the several RES-E share scenarios considered or even if we account for the entire domestic production of the RES-E basic equipment. The results herein achieved also allow concluding that with the maximization of RES-E production, energy imports, mainly of secondary energy, might be reduced as well as CO_2 emissions, showing the positive influence of RES-E on energy dependence and on the environment. Nevertheless, when the RES-E basic equipment is domestically produced, the maximization of RES-E production does not allow attaining the lower levels of CO_2 emissions or the lower levels of primary energy imports as it would be expected without further analysis, because of the high energy intensity of the activity sectors involved in the production of the inputs of these sectors. Although, at a local level RES-E production has the merit of CO_2 emissions reduction, at a national level the conclusion is not straightforward. On the other hand, the impact of RES-E on economic growth is not direct, since there is a trade-off highlighted with the solutions herein analyzed. In fact, this study brings to light the antagonist nexus between economic growth and RES-E production on one hand and the overall employment attained in the economy and the RES-E production on the other hand, particularly if the RES-E basic equipment is not mainly domestically produced. This fact indicates that the production of a significant part of the manufacturing activities domestically is an ideal prerequisite for maximizing the positive socio-economic effects of the development of RES-E in the Portuguese economy, albeit of some unrealistic nature.

Work is currently under way in order to encompass other impacts in this kind of models, namely the impacts of manufacturing and installing energy efficiency measures and the induced effects of energy savings and costs reduction. A thorough attention will also be paid to the choice of policies which have the greatest benefit to cost ratio and on how economic shifts/dislocations should be minimized.

Acknowledgments

This work has been framed under the Energy for Sustainability Initiative of the University of Coimbra and supported by Fundação para a Ciência e a Tecnologia (FCT) under project grants MIT/SET/0018/2009 and PEst-C/EEI/UI0308/2011, and R&D Project EMSURE - Energy and Mobility for Sustainable Regions (CENTRO 07 0224 FEDER 002004).

References

[1] Acciona, 2012. Amareleja photovoltaic solar unit. Worldwide reference for the development of renewable energies (in Portuguese). Available at: 〈http://www.acciona-energia.es/media/315790/Central%20solar%20fotovoltaica%20de%20Amareleja_Portugu%C3%A9s.pdf〉.
[2] ADENE, Re. New. Able., 2012. Available at: 〈http://www.renewable.pt/pt/RE/Paginas/agua.aspx〉.
[3] Blanco M, Rodrigues G. Direct employment in the wind energy sector: an EU study. Energy Policy 2009;37:2847–57.
[4] Borges AR, Antunes CH. A fuzzy multiple objective decision support model for energy-economy planning. European Journal of Operational Research 2003;145:304–16.
[5] Cai W, Wang C, Chen J, Wang S. Green economy and green jobs: Myth or reality? The case of China's power generation sector Energy 2011;36: 5994–6003.
[6] Cristóbal JR. A goal programming model for environmental policy analysis: application to Spain. Energy Policy 2012;43:303–7.
[7] Dias, A, E Domingos, 2011. Department of foresight and planning, Input–output matrices integrated systems for Portugal, 2008 (in Portuguese). Available at: 〈http://www.dpp.pt/Lists/Pesquisa%20Avanada/Attachments/3230/Matrizes_2008.pdf〉.
[8] Dorfman R, Samuelson P, Solow R. Linear programming and economic analysis. New York: Dover Publications, Inc.; 1958.
[9] EREC, Working for the climate. Renewable energy and green job revolution; 2009. Available at: 〈http://www.greenpeace.org/international/Global/international/planet-/report/2009/9/working-for-the-climate.pdf〉.

[10] EWEA, 2009. Wind at work. Wind energy and job creation in the EU. Available at: 〈http://www.ewea.org/fileadmin/ewea_documents/documents/publications/Wind_at_work_FINAL.pdf〉.
[11] Gay P, Proops J. Carbon-dioxide production by the UK economy: an input–output assessment. Applied Energy 1993;44:113–30.
[12] Hawdon D, Pearson P. Input–output simulations of energy, environment, economy interactions in the UK. Energy Economics 1995;17:73–86.
[13] INEGI, Portuguese endogenous energies, 2012. Available at: 〈http://e2p.inegi.up.pt/index.asp〉.
[14] IPCC, 2006. IPCC Guidelines for national greenhouse gas inventories: Energy, 2006. Available at: 〈http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol2.htm〉.
[15] Jennejohn D, Blodgett L, Gawell K. Geothermal energy and jobs. Geothermal Energy Association; 2009 Eds. Available at: 〈http://www.geo-energy.org/pdf/Geothermal_Energy_and_Jobs_Issue_Brief.pdf〉.
[16] Lambert J, Silva P. The challenges of determining the employment effects of renewable energy. Renewable and Sustainable Energy Reviews 2012;16:4667–74.
[17] Leontief W. Input–output analysis. In: Leontief W, editor. Input–output economics. New York: Oxford University Press; 1985. p. 19–40 Chapter 2.
[18] Ministry of Finance and Public Administration, 2011. Stability and growth programme 2011–2014, March (in Portuguese). Available at: 〈http://www.parlamento.pt/OrcamentoEstado/Documents/pec/21032011-PEC2011_2014.pdf〉.
[19] Mu T, Xia Q, Kang C. Input–output table of electricity demand and its application. Energy 2010;35:326–31.
[20] National Statistics Office, 2012. People serving entities producing environmental goods and services for each economic activity, according to sex and occupation and functions performed in the environmental field (in Portuguese). Available at: 〈www.ine.pt〉.
[21] Oliveira C, Antunes CH. A multiple objective model to deal with economy–energy–environment interactions. European Journal of Operational Research 2004;153:370–85.
[22] Oliveira C, Antunes CH. An interactive method of tackling uncertainty in interval multiple objective linear programming. Journal of Mathematical Sciences 2009;161:854–66.
[23] Oliveira C, Antunes CH. A multiobjective multi-sectoral economy energy–environment model: application to Portugal. Energy 2011;36:2856–66.
[24] Oliveira C, Antunes CH. Interactions of economic growth, energy consumption and the environment in the context of the crisis—a study with uncertain data. Energy 2012;48:415–22.
[25] Peet J. Energy requirements of output of the New Zealand economy, 1976–1977. Energy 1986;11:659–70.
[26] Proops J, Faber M, Wagenhals G. Reducing CO_2 emissions—a comparative input–output study for Germany and the UK. Germany: Springer -Verlag; 1993.
[27] Sastresa E, Usón A, Bribián I, Scarpelleni S. Local impact of renewable on employment: assessment methodology and case study. Renewable and Sustainable Energy Reviews 2010;14:679–90.
[28] Silva, P, C Oliveira Henriques, D Coelho, 2012. Employment effects and renewable energy policies: applying I–O methodology to Portugal, In: Proceedings of the 14th INFER annual conference, Coimbra, Portugal, 10–12 May.
[29] Tourkolias C, Mirasgedis S, Damigos D, Diakoulaki D. Employment benefits of electricity generation: a comparative assessment of lignite and natural gas power plants in Greece. Energy Policy 2009;37:4155–66.
[30] Wei M, Patadia S, Kammen D. Putting renewables and energy efficiency to work: how many jobs can the clean energy industry generate in the US? Energy Policy 2010;38:919–31.
[31] West Virginia Solid Waste Management Board, Economic Impact of Municipal Solid Waste Management in West Virginia, 2011. Available at: 〈http://www.state.wv.us/swmb/RMDP/2011StatePlan/Chapter9.pdf〉.